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NEWTON'S HYPOTHESES OF ETHER AND OF GRAVITATION FROM 1693 TO 1726.

AFTER his correspondence with Bentley and a letter of 1693 to Leibniz, referred to in §VI below, Newton does not seem to have made any more pronouncements about the ether or the nature of gravitation until the Latin edition of his *Opticks,* which was published in 1706. Discussions[1] on the cause of gravitation were greatly stimulated by the appearance of Newton's *Principia* in 1687, and continued — especially between Leibniz and Huygens — until 1694; but it would not be relevant to our present subject to consider these discussions further here.

We have seen that Newton himself did not regard gravitation as an essential property of matter, implanted in it by the Creator. In the *Principia,* he merely considered it as a starting-point for mathematical deductions; the discovery of its nature and cause was a physical and not a mathematical problem. From the letters of 1692 and 1693 to Bentley we learn that he did not pretend to know what the cause of gravity might be, but it seemed to him incomprehensible that matter should act on other matter without the intervention of a medium. Still he explicitly stated that he did not express any opinion as to "whether this agent be material or immaterial." In the first edition of the *Opticks* (1704) there was no mention in the "Queries" of the ether or gravitation.

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[1] Rosenberger, *Isaac Newton und seine physikalischen Principien,* pp. 227-248.

I.

In the preface to Newton's *Opticks*: *or, a Treatise of the Reflexions, Refractions, Inflexions, and Colours of Light,* which was published at London in 1704, he mentioned that the work consisted of: (1) The optical memoir of 1675; (2) Additions made in 1687; (3) Stray papers collected after this date into the third Book and the last proposition of the second Book. The printing of the work was delayed so that controversy might be avoided,[2] and even then it was only the importunity of his friends that led him to print at all. Newton's optical memoir of 1672 is not mentioned, and it is just possible that Newton's words: "If any papers writ on this subject are got out of my hands, they are imperfect and were perhaps written before I had tried all the experiments here set down, and fully satisfied myself about the laws of colors," refer to these memoirs.

The *Opticks* of 1704[3] is only hypothetical—at least intentionally[4]—in the "Queries" at the end. Of these[5] the first English edition only contained the first seven, the first sentence of the eighth, the ninth, the first two-thirds of the tenth, the first third of the eleventh, the twelfth to the fifteenth inclusive, and part of the sixteenth. The first Latin edition of 1706[6] contained in addition the second part of the eighth, the last third of the tenth, the last two-thirds of the eleventh, and the twenty-fifth to the thirty-first inclusive. The second English edition of 1717[7] contained in addition the last third of the eighth, the seventeenth to the twenty-fourth inclusive, and many additions to the thirty-first. Other editions (1718, 1721, 1730) published in Newton's lifetime or revised by Newton before his death contained various additions to and omissions from many of the queries, especially the last.[8]

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[2] Hooke died on March 3, 1703.

[3] German annotated translation by William Abendroth in Nos. 96 and 97 of *Ostwald's Klassiker* (Leipsic, 1898). An account of the contents of the *Opticks* is given by Rosenberger on pp. 294-301 of his book; the "Queries" were dealt with on pp. 301-327.

[4] See below, toward the end of the present section.

[5] Cf. Rosenberger, *op. cit.*, pp. 302-303.

[6] *Optice*: *sive de Reflexionibus, Refractionibus, Inflexionibus et Coloribus Lucis Libri Tres*; translated by Samuel Clarke, London, 1706. Other editions of this Latin translation were published in 1719, 1740, 1747, 1749, and 1773.

[7] *Opticks*: *or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light.* The Second Edition, with Additions. London, 1717.

Rosenberger[9] has remarked that "while in the *Opticks* of 1704 the observations and measurements are taken without any alteration, on account of their unsurpassed accuracy, from the great optical memoir of 1675, the theory, or rather the hypothesis which is its foundation, receives a completely new form. In the memoir of 1675, Newton still considered it likely that the rays of light excite vibrations in the ether contained in bodies when the rays meet this ether, and that these vibrations allow the transmission of light or cause its reflection according to the phase in which they meet the rays. In the *Opticks,* on the other hand, after he had had to let the ether drop, Newton considered rays of light without reference to any vibrations there may be in bodies and ascribed the alternating transmission and reflection of light which the colored rings indicate, merely to the internal nature of rays of light."

In fact, Newton began the book with the words: "My design in this book is not to explain the properties of light by hypotheses, but to propose and prove them by reason and experiments: in order to which I shall premise the following definitions and axioms."

In spite of this declaration, Newton was obliged, as Rosenberger[10] has pointed out, to attribute hypothetical properties to rays of light,—that the rays have "fits of easy transmission and reflection." But an addition (Query 17) to the second edition of 1717 explains these "fits" by the hypothesis of undulations which are excited in bodies by the rays of light.

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[8] This is practically what Rosenberger says; but the English edition of 1721 is unaltered from the second edition. The second edition is reprinted in Vol. IV of *Horsley.*

[9] *Op. cit.,* pp. 293-294.

[10] *Op. cit.,* p. 296.

With regard to Rosenberger's view that Newton was gradually forced to give up the assumption of an ether, this, as we shall see, is by no means likely if we consider Newton's own words without prejudice. Rosenberger, indeed, seems much too prone to attribute to Newton himself the views which some of his school held.

In the next section we will review those queries added to the edition of 1706 which have a bearing on our present subject. In the third section, we must consider the second edition (1713) of the *Principia.* In the fourth section we consider the relevant queries added to the edition of the *Opticks* published in 1717. In the fifth section reference is made to Newton's later (1716, 1725) remarks on Leibniz's criticism that he viewed gravitation as an "occult cause" and a "miracle"; and the sixth section deals with Newton's opinions on an ether and the nature of gravitation from the general point of view which has been reached.

II.

The twenty-seventh query is[11]

"Are not all hypotheses erroneous which have hitherto been invented for explaining the phenomena of light by new modifications of the rays? For those phenomena depend not upon new modifications, as has been supposed, but upon the original and unchangeable properties of the rays."

The long twenty-eighth query[12] begins:

"Are not all hypotheses erroneous in which light is supposed to consist in pression or motion propagated through a fluid medium? For in all these hypotheses the phenomena of light have been hitherto explained by supposing that they arise from new modifications of the rays, which is an erroneous supposition.

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[11] *Horsley,* Vol. IV, pp. 231-232. Cf. Rosenberger, *op. cit.,* p. 315.

[12] *Horsley,* Vol. IV, pp. 232-238. Cf. Rosenberger, *op. cit.,* pp. 315-318.

"If light consisted only in pression propagated without actual motion, it would not be able to agitate and heat the bodies which refract and reflect it. If it consisted in motion propagated to all distances in an instant, it would require an infinite force every moment in every shining particle to generate that motion. And if it consisted in pression or motion propagated either in an instant or in time, it would bend into the shadow. For pression or motion cannot be propagated in a fluid in right lines beyond an obstacle which stops part of the motion, but will bend and spread every way into the quiescent medium which lies beyond the obstacle.[13] Gravity tends downwards, but the pressure of water arising from gravity tends every way with as much force sideways as downwards and through crooked passages as through straight ones. The waves on the surface of stagnating water, passing by the sides of a broad obstacle which stops part of them, bend afterwards, and dilate themselves gradually into the quiet water behind the obstacle. The waves, pulses or vibrations of the air wherein sounds consist bend manifestly; though not so much as the waves of water. For a bell or a cannon may be heard beyond a hill which intercepts the sight of the sounding body, and sounds are propagated as readily through crooked pipes as through straight ones. But light is never known to follow crooked passages nor to bend into the shadow. For the fixed stars, by the interposition of any of the planets, cease to be seen. And so do the parts of the sun by the interposition of the moon, Mercury or Venus. The rays which pass very near to the edges of any body are bent a little by the action of the body, as we showed above; but this bending is not toward but from the shadow, and is performed only in the passage of the ray by the body and at a very small distance from it. So soon as the ray is past the body it goes right on."

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[13] *Principia,* Book II, Prop. XLII.

In the course of this query, Newton remarked:[14] "And against filling the heavens with fluid mediums, unless they be exceeding rare, a great objection arises from the regular and very lasting motions of the planets and comets in all manner of courses through the heavens. For thence it is manifest that the heavens are void of all sensible resistance and, by consequence, of all sensible matter."

Another part of the same query is:[15]

"And therefore to make way for the regular and lasting motions of the planets and comets it is necessary to empty the heavens of all matter, except perhaps some very thin vapors, steams or effluvia arising from the atmosphere of the earth, planets and comets, and of such an exceedingly rare ethereal medium as we described above. A dense fluid can be of no use for explaining the phenomena of nature, the motions of the planets and comets being better explained without it. It serves only to disturb and retard the motions of those great bodies and make the frame of nature languish. And in the pores of bodies it serves only to stop the vibrating motions of their parts wherein their heat and activity consists. And as it is of no use and hinders the operations of nature and makes her languish, so there is no evidence for its existence, and therefore it ought to be rejected. And if it be rejected, the hypotheses that light consists in pression or motion propagated through such a medium are rejected with it.

"And for rejecting such a medium we have the authority of the oldest and most celebrated philosophers of Greece and Phoenicia, who made a vacuum and atoms and the gravity of atoms the first principles of their philosophy, tacitly attributing gravity to some other cause than dense matter.

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[14] *Horsley,* Vol. IV, p. 234.

[15] *Horsley,* Vol. IV, pp. 236-238, Rosenberger, *op. cit.,* pp. 343-344.

Later philosophers banish the consideration of such a cause out of natural philosophy, feigning hypotheses for explaining all things mechanically and referring other causes to metaphysics: whereas the main business of natural philosophy is to argue from phenomena without feigning hypotheses and to deduce causes from effects till we come to the very first cause, which certainly is not mechanical; and not only to unfold the mechanism of the world, but chiefly to resolve these and such like questions. What is there in places almost empty of matter and whence is it that the sun and planets gravitate toward one another without dense matter between them? Whence is it that nature does nothing in vain; and whence arises all that order and beauty which we see in the world? To what end are comets, and whence is it that planets move all one and the same way in concentric orbits, while comets move all manner of ways in orbits very eccentric, and what hinders the fixed stars from falling upon one another? Does it not appear from phenomena that there is a Being incorporeal, living, intelligent, omnipresent, who in infinite space, as it were in his sensory, sees the things themselves intimately?" and so on.

In the twenty-ninth query, Newton[16] proceeded to develop his own emission-theory of light. It begins:

"Are not the rays of light very small bodies emitted from shining substances? For such bodies will pass through uniform mediums in right lines without bending into the shadow, which is the nature of the rays of light. They will also be capable of several properties and be able to conserve their properties unchanged in passing through several mediums, which is another condition of the rays of light."

"It is remarkable," said Rosenberger,[17] "that the statement [in this query] of the necessity of attractive forces and [in the preceding one] of the impossibility of an ether is followed by a reference intercalated in the edition of 1717, to the derivation of this attraction by means of this ether. This reference is: 'What I mean in this question by a *vacuum* and by the attraction of the rays of light towards glass or crystal may be understood by what was said in the 18th, 19th, and 20th questions.'[18] Apparently Newton wished to show, even in his queries, that his theories are reconcilable with all hypotheses...."

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[16] *Horsley*, Vol. IV, pp. 238-241. Cf. Rosenberger, *op. cit.*, pp. 319-321.

[17] *Op. cit.*, pp. 320-321.

It is obviously incorrect to speak, as Rosenberger does, of Newton's "statement...of the impossibility of an ether." As a rule, we have no means of deciding, from the "Queries," what Newton's real opinions on an ether were; but the letters to Bentley throw a great deal of light on the subject. Indeed, the weight of evidence seems to tell against Rosenberger's[19] view and in favor of the view which has become traditional, that Newton believed in some sort—not the Cartesian—of ether on the ground that he could not imagine a propagation of force without a medium.[20]

The thirtieth query[21] begins: "Are not gross bodies and light convertible into one another; and may not bodies receive much of their activity from the particles of light which enter their composition?" We know that for long after this, the matter of light was considered as a possible part of the subject-matter of chemistry.

The thirty-first query[22] was greatly added to in later editions, but we will here collect all that is said in it in its final form about the subjects that interest us at present. It begins:

"Have not the small particles of bodies certain powers, virtues or forces by which they act at a distance, not only upon the rays of light for reflecting, refracting and inflecting them, but also upon one another for producing a great part of the phenomena of nature? For it is well known that bodies act one upon another by the attractions of gravity, magnetism and electricity, and these instances show the tenor and course of nature and make it not improbable that there may be more attractive powers than these. For nature is very consonant and conformable to herself. How these attractions may be performed, I do not here consider. What I call attraction may be performed by impulse or by some other means unknown to me. I use that word here to signify only in general any force by which bodies tend toward one another, whatever be the cause. For we must learn from the phenomena of nature what bodies attract one another and what are the laws and properties of the attraction, before we inquire the cause by which the attraction is performed. The attractions of gravity, magnetism and electricity reach to very sensible distances and so have been observed by vulgar eyes, and there may be others which reach to so small distances as hitherto escape observation; and perhaps electrical attraction may reach to such small distances even without being excited by friction."

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[18] *Horsley,* Vol. IV, p. 241. These queries are given in § IV below.

[19] Cf. also *op. cit.,* pp. 333-334.

[20] Cf. § VI below.

[21] *Horsley,* Vol. IV, pp. 241-242. Cf. Rosenberger, *op. cit.,* pp. 321-322.

[22] *Horsley,* Vol. IV, pp. 242-264. Cf. Rosenberger, *op. cit.,* pp. 322-327.

"All bodies," said Newton,[23] "seem to be composed of hard particles." And again:[24] ". . . .it seems probable to me that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles of such sizes and figures and with such other properties and in such proportion to space[25] as most conduced to the end for which he formed them, and that these primitive particles being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces; no ordinary power being able to divide what God himself made one in the first creation. While the particles continue entire, they may compose bodies of one and the same nature and texture in all ages; but should they wear away or break in pieces, the nature of things depending on them would be changed. Water and earth composed of old worn particles and fragments of particles would not be of the same nature and texture now with water and earth composed of entire particles in the beginning. And therefore that nature may be lasting, the changes of corporeal things are to be placed only in the various separations and new associations and motions of these permanent particles; compound bodies being apt to break, not in the midst of solid particles but where those particles are laid together and only touch in a few points.

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[23] *Horsley,* Vol IV, p. 251.

[24] *Ibid.,* pp 260-262.

[25] "*Eoque numero et quantitate pro ratione spatii in quo futurum erat ut moverentur.* Dr. Clarke's first Latin; and so the sentence stands in Dr. Clarke's second Latin edition, which in most places was so corrected as to agree exactly with the second English. And to make sense of the passage, something is evidently wanting here to answer to the words of the Latin, *in quo futurum erat ut moverentur.* For to speak of particles of matter as bearing proportion to space indefinitely were absurd."—Note by Horsley.

"It seems to me further that these particles have not only a *vis inertiae* accompanied with such passive laws of motion as naturally result from that force, but also that they are moved by certain active principles, such as is that of gravity and that which causes fermentation and the cohesion of bodies. These principles I consider not as occult qualities, supposed to result from the specific forms of things, but as general laws of nature by which the things themselves are formed: their truth appearing to us by phenomena, though their causes be not yet discovered. For these are manifest qualities, and their causes only are occult. And the Aristotelians gave the name of occult qualities not to manifest qualities but to such qualities only as they supposed to lie hid in bodies and to be the unknown causes of manifest effects: such as would be the causes of gravity and of magnetic and electric attractions and of fermentations, if we should suppose that these forces or actions arose from qualities unknown to us and incapable of being discovered and made manifest. Such occult qualities put a stop to the improvement of natural philosophy, and therefore of late years have been rejected. To tell us that every species of things is endowed with an occult specific quality by which it acts and produces manifest effects, is to tell us nothing: but to derive two or three general principles of motion from phenomena, and afterwards to tell us how the properties of motion follow from phenomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in philosophy, though the causes of those principles were not yet discovered. And therefore I scruple not to propose the principles of motion above mentioned, they being of very general extent, and leave their causes to be found out.

"Now by the help of these principles, all material things seem to have been composed of the hard and solid particles above mentioned, variously associated in the first creation by the counsel of an intelligent Agent. For it became Him who created them to set them in order. And if he did so, it is unphilosophical to seek for any other origin of the world or to pretend that it might arise out of a chaos by the mere laws of nature; though being once formed, it may continue by those laws for many ages. For while comets move in very eccentric orbits in all manner of positions, blind Fate could never make all the planets move one and the same way in orbits concentric, some inconsiderable irregularities excepted, which may have arisen from the mutual actions of comets and planets upon one another, and which will be apt to increase till this system wants a reformation. Such a wonderful uniformity in the planetary system must be allowed the effect of choice. And so must the uniformity in the bodies of animals."

III.

Between the publication of the Latin translation and the second edition of the *Opticks* came that of the second edition of the *Principia* in 1713, which was very carefully edited by Roger Cotes.[26] Frequent mention of this edition has been already made in these articles:[27] what is of the greatest interest to us in this connection is that Newton, while emphasizing his neutral attitude toward the question as to whether *gravitation* was an essential property of bodies or no, added the famous *regulae philosophandi.* In the third rule, extension, hardness, impenetrability, mobility *and inertia* are classed together as universal qualities of bodies which can neither be increased nor diminished. In the second place, Cotes's preface, which expressed the views of Newton's school rather than of Newton himself, is usually supposed, and somewhat incorrectly supposed, to contain a distinct enunciation of the view—which Newton repeatedly disclaimed[28]—that gravity is an essential property of bodies.

Newton's own changes relating to our present subject in this edition have already been dealt with in §§ III and IV of my article in the April number of this magazine, and chiefly emphasize Newton's aversion to being supposed to state that gravity was an essential property of bodies. We will now fix our attention on Cotes's preface. In it is the passage:[29]

"Since, then, all bodies, whether upon earth or in the heavens, are heavy, so far as we can make any experiments or observations concerning them, we must certainly allow that gravity is found in all bodies universally. And just as we ought not to suppose that any bodies can be otherwise than extended, movable or impenetrable; so we ought not to conceive that any bodies can be otherwise than heavy. The extension, mobility and impenetrability of bodies become known to us only by experiments; and in the very same manner their gravity becomes known to us. All bodies we can make any observations upon are extended, movable and impenetrable; and thence we conclude that all bodies, even those concerning which we have no observations, are extended and movable and impenetrable. So we find that all bodies on which we can make observations are heavy; and thence we conclude that all bodies, even those of which we have no observations, are heavy also. If any one should say that the bodies of the fixed stars are not heavy because their gravity is not yet observed, he may say for the same reason that they are neither extended nor movable nor impenetrable, because these affections of the fixed stars are not yet observed. In short, either gravity must have a place among the primary qualities of all bodies, or extension, mobility and impenetrability must not. And if the nature of things is not rightly explained by the gravity of bodies, it will not be rightly explained by their extension, mobility and impenetrability.

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[26] See on this point, Edleston, *op. cit.*; Brewster, *op. cit.*, Vol. I, pp. 312-318; Vol. II, pp. 248-252, 254; Rouse Ball, *op. cit.*, pp. 124-135; Rosenberger, *op. cit.*, pp. 368-385.

[27] See *Monist* for October, 1914, § XV, and for April, 1915, § IV.

[28] It should be noticed that Newton expressly declined to see all of Cotes's preface lest he should be considered to be responsible for it (cf. Rosenberger, *op. cit.*, p. 373).

[29] Cf. Rosenberger, *op. cit.*, pp. 376-377.

"Some I know disapprove this conclusion, and mutter something about occult qualities.[30] They continually are caviling with us that gravity is an occult property and occult causes are to be quite banished from philosophy. But to this the answer is easy, that those are indeed occult causes whose existence is occult and imagined but not proved, but not those whose real existence is clearly demonstrated by observations. Therefore gravity can by no means be called an occult cause of the celestial motions; because it is plain from the phenomena that such a virtue does really exist. Those rather have recourse to occult causes who postulate imaginary vortices of a matter entirely fictitious and imperceptible by our senses to direct those motions. But shall gravity be therefore called an occult cause and thrown out of philosophy because the cause of gravity is occult and not yet discovered? Those who affirm this should be careful not to fall into an absurdity that may overturn the foundations of all philosophy. For causes are wont to proceed in a continuous chain from those that are more compounded to those that are more simple; and when we have arrived at the most simple cause, we can go no farther. Therefore no mechanical account or explanation of the most simple cause is to be expected or given; for if it could be given, the cause were not the most simple. These most simple causes will you then call occult and reject them? Then you must reject those that immediately depend upon them, and those which depend upon the last, till philosophy is quite cleared and disencumbered of all causes.

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[30] Leibniz in 1710 had accused Newton of introducing occult qualities and miracles into philosophy. On the subsequent controversy between Leibniz, Clarke, and others, see Brewster, *op. cit.*, Vol. II, pp. 282-289; Rosenberger, *op. cit.*, pp. 512-519.

"Some there are who say that gravity is preternatural and call it a perpetual miracle. Therefore they would have it rejected because preternatural causes have no place in physics. It is hardly worth while to spend time in answering this ridiculous objection, which overturns all philosophy. For either they will deny gravity to be in bodies, which cannot be said, or else they will call it preternatural because it is not produced by the other affections of bodies and therefore not by mechanical causes. But certainly there are primary affections of bodies, and these, because they are primary, have no dependence on the others. Let them consider whether all these are not in like manner preternatural, and in like manner to be rejected, and then what kind of philosophy we are like to have."

With this passage it is important to compare the following letter written by Cotes to Samuel Clarke. It is all the more important as it does not seem to be sufficiently emphasized by Rosenberger.[31]

Cotes wrote to Samuel Clarke[32] on June 25, 1713:[33]

"I received your very kind letter. I return you my thanks for your corrections of the Preface, and particularly for your advice in relation to that place where I seemed to assert gravity to be essential to bodies. I am fully of your mind that it would have furnished matter for caviling, and therefore I struck it out immediately upon Dr. Cannon's mentioning your objection to me, and so it never was printed. The impression of the whole book was finished about a week ago.

"My design in that passage was not to assert gravity to be essential to matter, but rather to assert that we are ignorant of the essential properties of matter, and that, in respect of our knowledge, gravity might possibly lay as fair a claim to that title as the other properties which I mentioned. For I understand by essential properties such properties without which no others belonging to the same substance can exist: and I would not undertake to prove that it were impossible for any of the other properties of bodies to exist without even extension."

The second edition of the *Principia* seems to have been published at the beginning of July, 1713. Edleston[34] thus commented on the above letter:

"It appears from the above letter that a meaning has been given to expressions in Cotes's Preface which he did not intend them to convey. He has been understood to assert that gravity is an essential property of bodies: his words are: '*Inter primarias qualitates corporum universorum vel*

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[31] *Op. cit.*, p. 374. But cf. pp. 381-382.

[32] On Clarke see Rosenberger, *op. cit.*, pp. 287-288.

[33] Edleston, *op. cit.*, pp. 158-159.

[34] *Ibid.*, pp. 159-160.

Gravitas habebit locum; vel Extensio, Mobilitas et Impenetrabilitas non habebunt.' " This passage is translated above.

IV.

The first notable change in the second English edition of 1717 was a second "Advertisement" dated July 16, 1717:

"And, to show that I do not take gravity for an essential property of bodies, I have added one question concerning its cause, choosing to propose it by way of a question because I am not yet satisfied about it for want of experiments."[35]

Queries eighteen to twenty are as follows:[36]

"Qu. 18. If in two large tall inverted cylindrical vessels of glass two little thermometers be suspended so as not to touch the vessels, the air be drawn out of one of these vessels, and these vessels thus prepared be carried out of a cold place into a warm one; the thermometer *in vacuo* will grow warm as much and almost as soon as the thermometer which is not *in vacuo*. And when the vessel is carried back into the cold place, the thermometer *in vacuo* will grow cold almost as soon as the other thermometer. Is not the heat of the warm room conveyed through the vacuum by the vibrations of a much subtler medium than air, which, after the air was drawn out, remained in the vacuum? And is not this medium the same as that medium by which light is refracted or reflected, and by whose vibrations light communicates heat to bodies, and is put into fits of easy reflection and easy transmission? And do not the vibrations of this medium in hot bodies contribute to the intenseness and duration of their heat? And do not hot bodies communicate their heat to contiguous cold ones by the vibrations of this medium propagated from them into the cold ones? And is not this medium exceedingly more rare and subtle than the air and exceedingly more elastic and active? And does it not readily pervade all bodies? And is it not (by its elastic force) expanded through all the heavens?

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[35] This declaration was probably drawn from Newton by the then recent controversy between Leibniz and Clarke. Cf. also *Macc. Corr.*, Vol. II, p.437. At the end of the preface to the second edition of the *Opticks* was added to the preface to the first edition the date: April 1, 1704. There is a similar peculiarity about the preface to the *Principia*; and Edleston (*op. cit.*, p. lxxi) remarked that the dispute with Leibniz about the invention of the calculus had probably taught Newton the importance of dates.

[36] *Horsley*, Vol. IV, pp. 223-224. Cf. Rosenberger, *op. cit.*, pp. 306-307.

"Qu. 19. Does not the refraction of light proceed from the different density of this ethereal medium in different places, the light receding always from the denser parts of the mediums? And is not the density thereof greater in free and open spaces void of air and other grosser bodies than within the pores of water, glass, crystal, gems, and other compact bodies? For when light passes through glass or crystal, and, falling very obliquely upon the farther surface thereof, is totally reflected, the total reflection ought to proceed rather from the density and vigor of the medium without and beyond the glass than from the rarity and weakness thereof.

"Qu. 20. Does not this ethereal medium, in passing out of water, glass, crystal and other compact and dense bodies into empty spaces, grow denser and denser by degrees, and by that means refract the rays of light not in a point but by bending them gradually in curve lines? And does not the gradual condensation of this medium extend to some distance from the bodies, and thereby cause the inflections of the rays of light which pass by the edges of dense bodies at some distance from the bodies?"

The twenty-first query runs:[37]

"Qu. 21. Is not this medium much rarer within the dense bodies of the sun, stars, planets, and comets than in the empty celestial spaces between them? And in passing from them to great distances, does it not grow denser and denser perpetually and thereby cause the gravity of those great bodies toward one another and of their parts toward the bodies, every body endeavoring to go from the denser parts of the medium toward the rarer? For if this medium be rarer within the sun's body than at its surface, and rarer there than at the hundredth part of an inch from its body, and rarer there than at the fiftieth part of an inch from its body, and rarer there than at the orb of Saturn; I see no reason why the increase of density should stop anywhere and not rather be continued through all distances from the Sun to Saturn and beyond. And though this increase of density may at great distances be exceeding slow, yet if the elastic force of this medium be exceeding great it may suffice to impel bodies from the denser parts of the medium towards the rarer with all that power which we call gravity. And that the elastic force of this medium is exceeding great may be gathered from the swiftness of its vibrations. Sounds move about 1140 English feet in a second of time, and in seven or eight minutes of time they move about one hundred English miles. Light moves from the sun to us in about seven or eight minutes of time, which distance is about 70,000,000 English miles, supposing the horizontal parallax of the sun to be about 12 seconds. And the vibrations of pulses of this medium, that they may cause the alternate fits of easy transmission and easy reflection, must be swifter than light, and by consequence above 700,000 times swifter than sounds. And therefore the elastic force of this medium in proportion to its density must be above 700,000 times 700,000 (that is, above 490,000,000,000) times greater than the elastic force of the air is in proportion to its density. For the velocities of the pulses of elastic mediums are in a subduplicate ratio of the elasticities and the rarities of the mediums taken together.

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[37] *Opticks*, 1721, pp. 325-327; *Horsley*, Vol. IV, pp. 224-225. Cf. Rosenberger, *op. cit.*, pp. 307-308.

"As attraction is stronger in small magnets than in great ones in proportion to their bulk, and gravity is greater in the surfaces of small planets than in those of great ones in proportion to their bulk, and small bodies are agitated much more by electric attraction than great ones, so the smallness of the rays of light may contribute very much to the power of the agent by which they are refracted. And so if any one should suppose that ether (like our air) may contain particles which endeavor to recede from one another (for I do not know what this ether is) and that its particles are exceedingly smaller than those of air or even than those of light, the exceeding smallness of its particles may contribute to the greatness of the force by which those particles may recede from one another, and thereby make that medium exceedingly more rare and elastic than air and by consequence exceedingly less able to resist the motions of projectiles and exceedingly more able to press upon gross bodies by endeavoring to expand itself."

The twenty-second query is:[38]

"May not planets and comets and all gross bodies perform their motions more freely and with less resistance in this ethereal medium than in any fluid which fills all space adequately without leaving any pores, and by consequence is much denser than quicksilver or gold. And may not its resistance be so small as to be inconsiderable? For instance, if this ether (for so I call it) should be supposed 700,000 times more elastic than our air and above 700,000 times more rare, its resistance would be above 600,000,000 times less than that of water. And so small a resistance would scarce make any sensible alteration in the motions of the planets in ten thousand years. If any one would ask how a medium can be so rare, let him tell me how the air in the upper parts of the atmosphere can be above hundred thousand times rarer than gold. Let him also tell me how an electric body can by friction emit an exhalation so rare and subtle and yet so potent as by its emission to cause no sensible diminution of the weight of the electric body, and to be expanded through a sphere whose diameter is above two feet and yet to be able to agitate and carry up leaf-copper or leaf-gold at the distance of above a foot from the electric body? And how the effluvia of a magnet can be so rare and subtle as to pass through a plate of glass without any resistance or diminution of their force, and yet so potent as to turn a magnetic needle beyond the glass?"

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[38] *Horsley*, Vol. IV, pp. 225-226; Rosenberger, *op. cit.*, pp. 308-309.

To base on the eighteenth query to the twenty-second query an opinion that as time went on Newton inclined more and more to the undulatory theory of light with its necessary assumption of an ether, and here, in 1717, denied the doctrine of his school which asserted action at a distance is, according to Rosenberger,[39] incorrect. It seems true that Newton, for what were then good reasons, never abandoned the emission theory. It is also true that the hint as to the derivation of gravitation from different densities of the ether is merely vague. But this does not prove that Newton had not a decided leaning toward the notion that action was always propagated by a medium. But Rosenberger makes a very apposite remark when he states that the matter of these "Queries" is taken from the "Hypothesis" of 1675 and the letter to Boyle of 1679. It may be that these old speculations were again brought forward to show that Newton had studied theories of the ether as carefully as his opponents—Leibniz and the Cartesians.[40]

Finally, an addition to the twenty-ninth query is referred to in § II above.

V.

In a letter of February 26, 1716,[41] to the Abbé Conti,

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[39] *Op. cit.*, pp. 309-311.

[40] *Ibid.*, p. 311.

[41] *Horsley*, Vol. IV, p. 597; Brewster, *op. cit.*, Vol. II, pp. 288-289; Rosenberger, *op. cit.*, pp. 382-383.

Newton commented on Leibniz's use,[42] in 1710, of the terms "occult causes" and "miracles"; but Newton's remarks are not of much importance. This was[43] also dwelt upon in the unsigned preface to the edition of the *Commercium Epistolicum* published in 1725, and this preface is known[44] to have been written by Newton himself.

Finally, in the third edition of the *Principia,* which was edited by Henry Pemberton and published in 1726,[45] there is, as we saw in § IV of my article in *The Monist* for April, 1915, one addition emphasizing Newton's wish not to be understood as asserting that gravity was an essential property of bodies.

VI.

Rosenberger[46] says: "It results quite clearly from Newton's utterances that he held that a kinetic or even a physical explanation of gravity as an effect brought about by an intervening medium is impossible. In the *Principia* he decisively refuted the possibility of an explanation of gravity and the celestial motions by Descartes's vortices. But he also refuted the many attempts at the improvement of this doctrine which were given at that time by destroying their fundamental supposition—that there exists an ethereal matter which fills all space—by his researches on the resistance which this matter must present to the celestial motions. It might have been urged that by this the impossibility of an ether in general was not proved: only of one whose density could be measured by us. It might have been urged that Newton himself admitted a light-matter which is distributed everywhere like light and must thus just like the ether hinder the motions of the planets. But Newton explained that his corpuscles are much too thinly distributed in space for their resistance to be sensible, while the Cartesian ether, which completely fills space, must under all circumstances give rise to a very great resistance."

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[42] See above, § III.

[43] Rosenberger, *op. cit.,* pp. 383-384.

[44] Brewster, *op. cit.,* Vol. II, p. 75.

[45] Cf. Brewster, *op. cit.,* Vol. II, pp. 378-384, 549-556; Rouse Ball, *op. cit.,* pp. 135-136.

[46] *Op. cit.,* p. 409.

Newton's views on the subjects which concern us at present are thus summarized by Rosenberger.[47]

"All particles of matter accessible to our senses and all bodies move as if they attracted one another in the direct ratio of their masses and the inverse ratio of the squares of their distances from one another. This mutual action is not action at a distance but is brought about by some intermediary not yet certainly to be determined. Since, however, a matter suitable to play the part of this intermediary cannot be found, this agent is probably immaterial and in all likelihood God himself. It is doubtful whether God does this directly or indirectly, though probably the former. Hence follows that the mutual action in all matter is not an essential and necessary property of it like impenetrability and mobility, but a quality given to matter by the creator in perfect freedom and in the way which seemed proper to him."

It is not impossible that this was Newton's real view. But it seems impossible to doubt that Newton decidedly leaned toward the hypothesis of a very rare ether. Certainly he thought that he had refuted the Cartesian theory of a dense ether. And Newton himself has given some further indication of what his views were, and this indication seems, like the letters to Bentley, to support our conjecture. Leibniz had asked Newton what was his opinion of what Huygens had said in the appendix, *Discours de la Cause de la Pesanteur,* to his *Traité de la Lumière* of 1690. On October 26, 1693, Newton replied:[48]

"I cannot admit that a subtle matter fills the heavens, for the celestial motions are too regular to arise from vortices, and vortices would only disturb the motion. But if any one should explain gravity and all its laws by the action of some subtle mediums, and should show that the motions of the planets and comets were not disturbed by this matter, I should by no means oppose it."

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[47] *Op. cit.*, p. 422.

[48] Mentioned in another connection by Rosenberger, *op. cit.*, pp. 461-462.

It would seem that Newton felt just as strongly as did Descartes or Huygens or Leibniz or Faraday or Maxwell a need for a medium by which to transmit force. A weapon sometimes used against Cartesian doctrines by those whose interests or emotions led them to condemn what they fancied might be construed as a slight on the omnipotence of God, was that Descartes's world was so planned as to leave God out of account altogether. But something like this is the ideal of every scientific man. However pious a man of science may be—and some even eminent men of science have been models of unthinking devotion to certain religious sects — he will try to explain by natural causes phenomena which have hitherto appeared inexplicable except as miracles wrought by God. It is difficult to imagine that religious belief could ever interfere with this postulate of scientific investigation, and thus it can hardly be believed that Newton preferred to help himself out by supposing certain actions on the part of God, when there was a chance that gravitation might be explained by the hypothesis of a rarefied ether.

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